Gartner Lee Associates Limited

Consulting Engineering Geologists and Hydrogeologists

Toronto-Buttonville Airport ■ Markham, Ontario ■ L3P 3J9 ■ 416-477-8400
Telex - 06-986278

STAGE 1 REPORT
HYDROGEOLOGICAL STUDY
SOUTH CAYUGA SITE

PROJECT NO. 81-1018

JANUARY, 1982

DISTRIBUTION:

50 CC: CLIENT
5 CC: FILE

Gartner Lee Associates Limited

Consulting Engineering Geologists and Hydrogeologists

Toronto-Buttonville Airport ■ Markham, Ontario ■ L3P 3J9 ■ 416-477-8400
Telex - 06-986278

January 25, 1982.

Dr. D. A. Chant,
Chairman and President,
Ontario Waste Management Corporation,
Suite 707,
60 Bloor Street West,
Toronto, Ontario.
M41 1A1.

Dear Dr. Chant:

Re: Stage 1 Report -
Hydrogeological Study
South Cayuga Site

We respectfully present our report on the findings of the Stage 1 hydrogeological studies for the South Cayuga Order-in-Council lands.

The report contains a description of the background of the study, its purposes, scope and the conditions encountered during the investigation. We describe our scientific method of approach and briefly list the results of our investigations of the geological and hydrogeological conditions. In Section 4.0 of the report we discuss our interpretation of the results followed by our conclusions regarding suitability for a secure landfill. The conclusions and interpretation are summarized in the following paragraphs.

It is our understanding that the Corporation requires a long-term facility of contiguous area. Further, the facility should be such that flexibility of disposal options can be realized.

The Order-in-Council lands encompass 1870 hectares. Our

continued ..

Stage 1 investigations have shown that about half of the lands are unsuitable for disposal. Constraints in these lands, identified during our studies are; shallow depth to bedrock, flood-prone lands and drumlins.

The remaining lands are known to contain drumlins buried below the clay, but the location and number of such drumlins are at present unknown. Geological conditions such as these limit the flexibility of disposal methods on the lands and in this context the Order-In-Council lands are judged to be marginally suitable. These concerns lead to unpredictable factors associated with contaminant migration.

Even if 40 contiguous hectares could be found with no buried drumlins, the disposal options would be limited. Depending on the option chosen, the life of the site could be shortened. For example, if entombment is a desired disposal option, then the excavation depth and area requirements become constraints at this site for a long-term facility.

We would like to thank the Corporation and its staff for their co-operation during this Stage I study.

Respectfully submitted,

GARTNER LEE ASSOCIATES LIMITED

P. K. Lee, M.A.Sc., P.Eng.
Consulting Engineering Geologist,
Partner-In-Charge.

E.G. Anderson, P.Eng.,
Consulting Hydrogeologist.
Project Director.

PKL:jcm

ABBREVIATIONS

The following abbreviations are used throughout this report. Metric units follow the Canadian Metric Practice Guide published by the Canadian Standards Association (CAN3-Z234.1-79).

a	...	year
a.s.l.	...	above sea level
g	...	gram
ha	...	hectare
kg	...	kilogram
kg/m^3	...	kilogram per cubic metre
L	...	litre
L/a	...	litre per year
L/s	...	litre per second
m	...	metre
m^2	...	square metre
m^3	...	cubic metre
mm	...	millimetre
m/a	...	metre per year
m/s	...	metre per second
m^3/a	...	cubic metre per year
meq	...	milliequivalent
meq/L	...	milliequivalent per litre
s	...	second
t	...	tonne

TABLE OF CONTENTS

	Page
Letter of Transmittal	
Abbreviations	
1.0 INTRODUCTION:	1
1.1 Background	1
1.2 Purpose & Scope	5
1.3 Previous Work and Acknowledgements	7
1.4 Secure Landfill Concepts	8
2.0 METHODOLOGY:	10
2.1 Approach - Suitability Analysis	10
2.2 The Data Base	11
2.3 Office Studies	13
2.4 Field Work	14
2.5 Presentation of Results	15
3.0 DESCRIPTION OF THE SOUTH CAYUGA STUDY AREA:	16
3.1 Location of the Study Area	16
3.2 Physiography	17
3.3 Topography	17
3.4 Drainage	17
3.5 Geology	19
3.5.1 BEDROCK GEOLOGY	19
3.5.2 QUATERNARY GEOLOGY AND TERRAIN	20

	PAGE
3.6 HYDROGEOLOGY	23
3.6.1 HYDROSTRATIGRAPHIC UNITS	23
3.6.2 THE FLOW SYSTEM	24
3.6.3 GROUND WATER FLOW VELOCITIES	25
3.6.4 GROUND WATER QUALITY AND USE	26
3.7 GAS WELLS	27
4.0 DISCUSSION OF RESULTS:	29
4.1 PREFACE	29
4.2 SITE SUITABILITY	30
5.0 CONCLUSIONS:	34
6.0 GLOSSARY OF SELECTED TERMS:	36
7.0 SELECTED BIBLIOGRAPHY:	40

APPENDICES:

APPENDIX I: FIELD OBSERVATIONS

APPENDIX II: HYDROSTRATIGRAPHIC UNITS AND HYDROGEOLOGICAL CALCULATIONS

PAGE

LIST OF FIGURES:

FIGURE 1	-	KEY MAP	3
FIGURE 2	-	SITE PLAN	4
FIGURE 3	-	SUMMARY OF PHYSICAL CONDITIONS	(BACK POCKET)
FIGURE 4	-	SCHEMATIC CROSS SECTION	22
FIGURE 5	-	SUBSURFACE DATA POINTS	(BACK POCKET)

INTRODUCTION

1-0

1.0 INTRODUCTION:

1,1 BACKGROUND:

As described in a report by MacLaren Engineers Planners and Scientists Inc. (1980), Ontario's industrial activities presently generate 270,000 to 320,000 tonnes of liquid industrial waste and hazardous waste per year.

Concerns for pollution of ground and surface water at landfills, not originally intended to take these types of wastes nor designed to today's standards, have been raised. As well uncertainties exist with regard to continued American acceptance of Ontario's liquid industrial waste. These concerns prompted the Ministry of the Environment in October, 1978 to propose the Seven-Point Program to provide management of liquid industrial waste and hazardous waste for Ontario.

One of the key commitments of the Seven-Point Program was to produce a plan for various facilities in Ontario. To fulfill this commitment, a study was commissioned in April, 1979, the purpose of which was to develop an overall management plan for Ontario's liquid industrial waste and hazardous waste including the selection of suitable site(s), for treatment/disposal complexes.

Subsequent to the release of the report on "Siting of

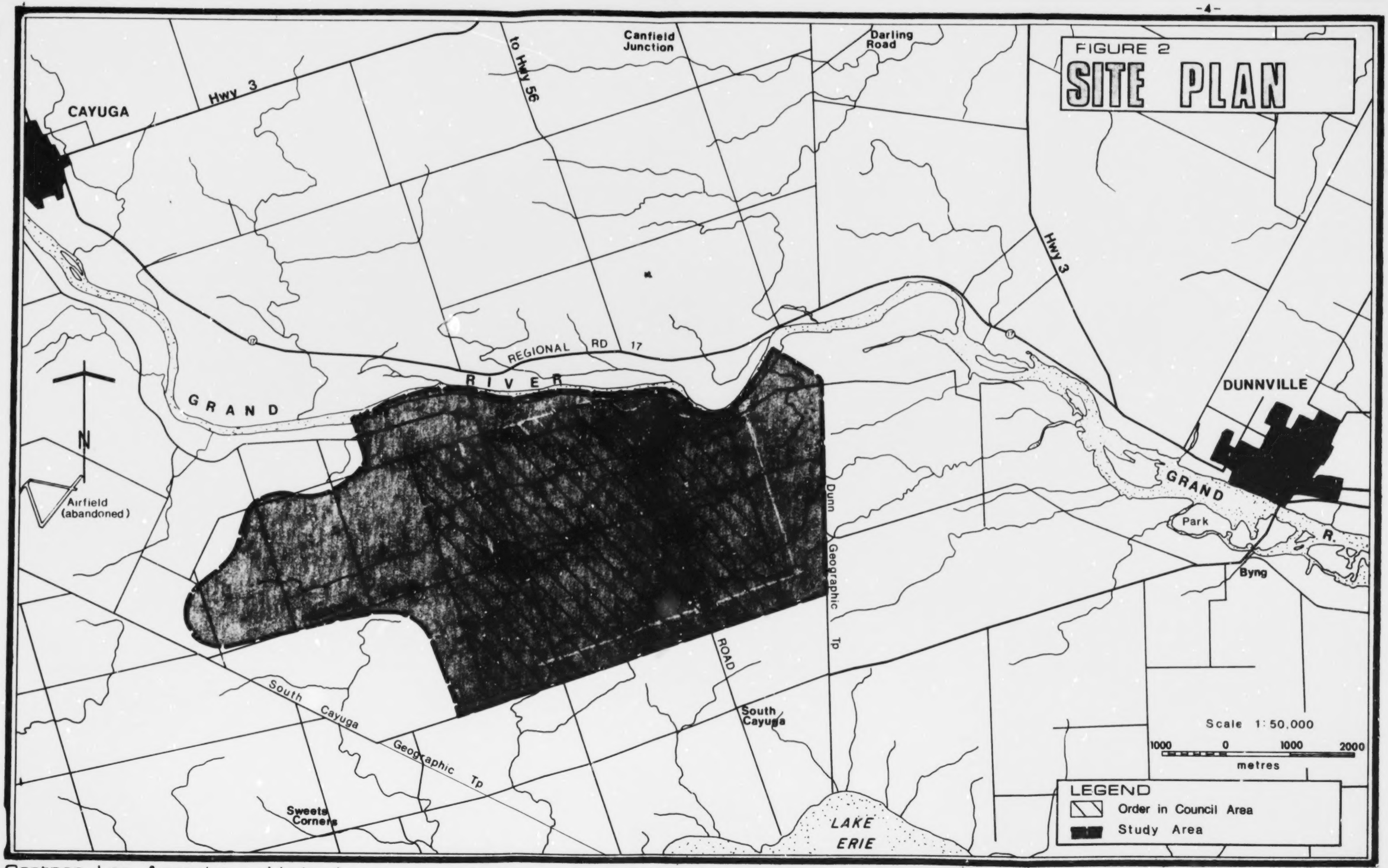
Facilities and the Management of Liquid Industrial and Hazardous Wastes in Ontario" by MacLaren in November, 1980, the then Minister of the Environment, the Honourable H.C. Parrott, D.D.S., announced the establishment of a permanent facility to store, treat and dispose of liquid industrial waste and hazardous waste at South Cayuga, Figure 1. The Ontario Waste Management Corporation (OWMC) was formed to provide safe and comprehensive, suitable waste management facilities and to manage the new facility operations.

In response to a request for proposals from the O.W.M.C., issued on March 31, 1981, Gartner Lee Associates Limited in conjunction with International Environmental Consultants Limited submitted a "Proposal For Consulting Services - South Cayuga Hydrogeological and Related Studies". This document that recommended a staged approach was accepted and a contract was signed on May 20, 1981, authorizing Gartner Lee Associates Limited to proceed with Stage 1 of the program. This report presents our findings of that Stage 1 Study. At this time the OWMC Board of Directors has decided not to proceed with the detailed "Stage 2" follow-up work on the South Cayuga property.

The Order-in-Council dated April 9, 1981, delineates the Order-in-Council boundaries, as shown on Figure 2. Because natural features and conditions often transcend man-made boundaries our hydrogeological study extended beyond these boundaries as also shown on Figure 2.

FIGURE 2

SITE PLAN



Gartner Lee Associates Limited

Fig. 1
N
0
10
20
km
Brampton
401
TORONTO
Canada
U.S.A.
LAKE
ONTARIO
Oakville
QEW
6
Burlington
HAMILTON
Niagara-on-the-Lake
St.
Catharines
Niagara
Falls
Niagara R.
Grand
R.
56
20
S. Cayuga Site
Welland
Cayuga
3
58
Fort Erie
Dunnville
Nanticoke
Port
Colborne
LAKE ERIE

KEY MAP

1.2 PURPOSE AND SCOPE:

The purpose of this Stage 1 study was:

(i) to describe the existing hydrogeological setting of the South Cayuga Site and show its relationship to the surrounding lands and drainage,

(ii) to determine at an early stage if the South Cayuga Site was generally suitable for the development of a secure landfill facility from a hydrogeological point of view.

Stage 1 was intended to provide a basis for future action at the site with an emphasis on the terrain and hydrogeology. If the results of Stage 1 were positive then it would serve as a reference framework for Stage 2, a more detailed and comprehensive follow-up.

The purpose of Stage 2 was:

(i) to document comprehensively and from first-hand knowledge the existing hydrogeological and biophysical setting of the site,

(ii) to determine the locations within the site for secure landfill facility options and alternatives.

At the end of Stage 2 when the engineering options had

been decided upon, then a further Stage 3 study would be completed to obtain specific design parameter details and monitoring data. As noted earlier each stage would serve as a basis for the one that followed dependent upon the findings. At this time the program has been terminated at the end of Stage 1.

The tasks in Stage 1 were originally intended to be based on the collation, interpretation and analysis of existing data on terrain and subsurface conditions. This was to be followed closely by a field work phase. Unfortunately, access problems delayed the field studies for about three months, until late September 1981. The original field work program was also enlarged beyond the original Terms of Reference to incorporate the digging of backhoe test pits to examine soil physical properties, especially the fracturing of the surface clays and subsoils. A series of meetings in October and November of 1981 were used to relay our findings to the OWMC and information provided at these meetings contributed to the formulation of their decision on the South Cayuga Site in mid-November 1981.

Also inherent in evaluating the suitability of the site for disposal is background data regarding the nature of the waste materials, such as their quantity and characteristics. Leachate aspects must also be considered. Preliminary information in these matters was supplied by Proctor & Redfern Limited and OWMC staff.

1.3 PREVIOUS WORK AND ACKNOWLEDGEMENTS:

The subject area in South Cayuga Township has been included in several studies, reports and maps. The reader is referred to Section 7.0 of this report for the bibliography since only the highlights are noted here.

The bedrock geology mapping by Telford & Tarrant (1975) (Section 7.0 Selected Bibliography) included this area. Bedrock topography and drift thickness maps, published by the Ontario Geological Survey, also cover the area.

The regional physiography has been described and mapped by Chapman and Putnam (1966). Quaternary mapping by B. Feenstra (1974) of the Ontario Geological Survey dealt with glacial soils, stratigraphy and landforms. Pedologic soil mapping was provided by the report and maps of Patterson (1978). The Ministry of the Environment published a Ground Water Probability Map (1974) for the County of Haldimand.

The South Cayuga Site was described in the MacLaren Engineers Planners and Scientists Inc. report entitled "Siting of Facilities and the Management of Liquid Industrial and Hazardous Wastes in Ontario" produced in 1980 for the Ministry of the Environment.

In the fall of 1980, the consulting firm of Morrison Beatty Limited carried out a hydrogeological drilling program and report on part of the South Cayuga site for the Ontario Land Corporation.

Several groups and individuals also supplied information to provide a more complete base. Thanks are especially extended to local residents who met with our staff in the course of our field activities. Other groups who were particularly helpful were:

- Haldimand-Norfolk Organization for a Pure Environment (HOPE)
- Ontario Council of Commercial Fisheries (East Lake Erie Trawlers Association)
- Federation of Agriculture (Haldimand Branch)
- Town of Dunnville
- Town of Haldimand
- Regional Municipality of Haldimand-Norfolk
- Hazardous Waste Information Service (OPIRG - Dunnville)

1.4 Secure Landfill Facility Concepts:

In the present study the overall objective is to assess whether the South Cayuga Site is suitable or not for development of a secure landfill facility.

The secure landfill concept is inherently related to the philosophy of containment and leachate collection and management. This type of facility involves an engineered system to control hydraulic gradients and leachate within the landfill, i.e. a mechanical operation. Management time frames are related to the stabilization of leachate,

with perpetual care being a likelihood. Leachate collection and treatment are required along with discharge of a treated acceptable effluent to surface water and the re-landfilling of the residue. In this way neither the wastes nor their leachate leave the site with the exception of an acceptable effluent.

Conventional landfill development consists of excavating and backfilling with wastes. Final site grades usually are above the pre-landfill elevations resulting in a surface mound of wastes. This type of operation necessitates long term maintenance of the above-surface landform to ensure that erosion of the final cover does not occur and leachate breakout, either at the toe, resultant from water table mounding, or on the side slopes from perched springs, does not occur.

Entombment, on the other hand, is less widely used, primarily because of a need for more acreage to achieve the same capacity as compared to conventional filling described above. This concept consists of burying wastes below the existing ground surface. As a consequence, erosion of the final cover, water table mounding and leachate breakout can be virtually eliminated.

Although perpetual maintenance and monitoring will be required using either operational technique, the amount of maintenance and monitoring could be considerably less utilizing the latter technique.

METHODOLOGY

2-0

2.0 METHODOLOGY:

2.1 APPROACH - SUITABILITY ANALYSIS:

The analysis of Stage 1 findings allows us to make certain qualified judgements on the suitability of the Order-in-Council lands for a secure landfill. Flexibility of landfill options is dependent upon the hydrogeological setting and the site suitability philosophy is based on the predictability of this. Hence to properly site a secure landfill facility, the hydrogeological setting must have the following characteristics:

(i) The natural setting on surface and at depth should be predictable from both a geology (materials) and a hydrogeology point of view.

(ii) In the event of an engineering failure or an accidental spill, the hydrogeological environment must provide sufficient lead time in terms of contaminant migration to allow its proper investigation and development and implementation of remedial technology.

(iii) If contaminant migration does occur from the facility, the geological materials must effectively retard and attenuate the fluids by physico-chemical processes.

Therefore the approach is based on the predictability of

a safe suitable natural setting rather than upon a check list of parameters. In this way the inter-relationships and their resultant significance are stressed rather than individual or specific criteria, for example, depth to water table or percent clay.

Also inherent in assessing the suitability of any site is the nature of the waste and its by-products. The life of the site, the volume of the space needed as well as the assessment of leachate impacts is predicated upon the characterization of the waste (i.e. chemical and physical characteristics, quantity etc.). This characterization is beyond the scope of the present work and preliminary information was supplied by OWMC staff and Proctor & Redfern Limited.

In order to assess the suitability at this stage, a reference framework of the existing setting was developed and interpreted for its predictability. The data base was developed from the re-interpretation of existing data supplemented in part by field work. The results of this preliminary evaluation would receive further scrutiny and confirmation by subsequent first hand multi-disciplinary follow-up work if the site were shown suitable at this stage.

2.2 The Data Base:

Information that was collected and plotted onto maps is listed here. The base maps have a scale of 1:10,000. A

list of references on resource information is provided for the reader in Section 7.0. The base maps developed in the study are:

(i) Flood Conditions
(ii) Isopachs of Overburden
(iii) Bedrock Contours
(iv) Quaternary Geology
(v) Terrain Conditions
(vi) Location of Water Wells
(vii) Location of Gas Wells
(viii) Location of Morrison Beatty drill holes
(ix) Topography
(x) Land Use
(xi) Ground Water Flow in Bedrock Aquifer
(xii) Drainage Conditions

As well, the data base includes hydrogeological cross-sections, tables, figures and calculations related to the setting. The data base also includes input from interviews with people knowledgeable about the area. The base is then a compilation of previous scientific works, local knowledge and our own interpretation, observation and analysis.

All sources provide important information. As an example of the scientific base information, the logs of the gas wells, water wells and previous boreholes allowed us to plot the contours of the bedrock surface. On the other hand, local knowledge and the provision of photographs taken during a time of recent flooding allowed us to

estimate the approximate limits of flood-prone lands.

2.3 Office Studies:

The office study commenced with a literature search and review of all available information as shown in Section 7.0. These involved:

(i) geology maps and reports both Quaternary and bedrock
(ii) pedological soils data
(iii) physiographic reports and maps
(iv) Ontario Ministry of the Environment ground water reports and water well records
(v) Ontario Ministry of Natural Resources gas well logs and reports
(vi) site-specific reports (MacLaren, Morrison Beatty and Ministry of Transportation and Communications)
(vii) flood line mapping
(viii) aerial photographs
(ix) relevant hydrogeological reports and papers

The available raw data was analyzed and integrated by experienced geologists and hydrogeologists onto a series of maps and overlays to examine both surface and sub-surface conditions (as described in Section 2.2). Airphotos were stereoscopically interpreted to provide terrain details of surficial soils, slopes, drainage, land use etc.

Cross-sections were developed using geological and hydro-

geological data to analyze stratigraphy and ground water movement within the study area.

Once the setting was established ground water fluxes were calculated and scenarios of contaminant migration were examined using the classical flow system approach. Fracture flow was assumed in the weathered zone. Because of the very slow velocities in the clays an analysis using diffusion as described by Desaulniers et.al. (1981) in a similar situation was also used. Finally, attenuation aspects were examined. The details of this information are provided in Appendix 2.

2.4 FIELD WORK:

The office study provided a reference framework on which to base the field work. Since the Stage 1 work was based largely upon existing information sources, it was felt necessary to ground truth and field check to confirm the data base as much as practical.

Geological mapping, including hand auger work, was completed. Test pits were dug to evaluate the upper 4 m of soil for consistency and to examine desiccated fractures in these soils. Interviews were held with residents within the Order-in-Council lands to obtain information on water well conditions. Finally, water level readings were recorded in the monitors left by the previous Morrison Beatty Limited work. These data are appended for reference.

2.5 PRESENTATION OF RESULTS:

The foregoing describes the method of problem solving used to assess the suitability of the Order-in-Council lands. The resulting bulk of data and maps has not been included here. These have been retained on file as working documents for future reference.

A final map has been prepared to show the conditions that are directly relatable to secure landfill suitability. Only one cross-section has been included in the text and this is of a conceptual nature only to explain general geologic stratigraphy at depth.

The appendix contains the field observations that were developed by our staff in the present work; e.g. backhoe test pit logs, water levels. A further map shows the locations of water wells, test holes by others, gas wells etc. As with our other data these observations by others are not included here but are retained in our working files for reference.

DESCRIPTION OF THE SOUTH CAYUGA STUDY AREA

3-0

3.0 DESCRIPTION OF THE SOUTH CAYUGA STUDY AREA:

This section provides a description of the existing setting of the subject lands with an emphasis on their relationship to secure landfill and hydrogeology. The description provides pertinent highlights and is not intended to describe in detail particular facets, for example, Quaternary geology. The reader is referred to Section 7.0 if reference detail is required.

3.1 LOCATION OF THE STUDY AREA:

The 1870 hectares of the Order-in-Council lands are shown on Figure 2, the Site Plan. The study area is also shown on the figure and this boundary is based more on physical conditions needed for analysis than on man-made limits.

The Order-in-Council lands are on parts of Lots 10 to 21, Concession 4 and Lots 10 to 21 of Concession 5, in the former Township of South Cayuga, County of Haldimand. This area is now in the Town of Haldimand in the Regional Municipality of Haldimand-Norfolk. The Order-in-Council lands are referred to here as "the South Cayuga Site". The key plan Figure 1 shows its relationship to the major urban areas of Toronto, Hamilton and St. Catharines.

3.2 PHYSIOGRAPHY:

The landforms associated with the subject lands have been described generally by Chapman & Putnam (1966). The area falls within their Haldimand Clay Plain physiographic region where it borders the Grand River Valley. The Onondaga Bedrock Escarpment cuts through the site.

3.3 TOPOGRAPHY:

The Onondaga Escarpment cuts the study area into two parts. The lands on top of the escarpment (to the south) form a nearly flat plateau with elevations ranging from 196 m to 205 m a.s.l. Slopes range up to 2 percent. Below (north of) the Onondaga Escarpment elevations range from 184 m to 190 m a.s.l. Although the changes in elevation of the area in general are minor, there is local hummocky micro-relief. The hummocks range as high as 5 m and local slopes may be as high as 10 percent.

3.4 DRAINAGE:

The main Lake Erie-Grand River drainage divide crosses the southern portion of the Order-in-Council lands. South of this line drainage is towards Lake Erie. North of the divide, the lands drain into the Grand River. Robinson Creek which crosses the site and flows from west to east, drains into the Grand River and forms the largest single sub-watershed of the study lands. On the east portion of these

lands, drainage is easterly to the Grand River via a number of small drainage channels. The Grand River is at an elevation of about 175 m a.s.l. at the study area. Lake Erie has an approximate water level of 174 m a.s.l.

The clay soils that cover the Order-in-Council lands have resulted in the development of an integrated, dendritic drainage pattern. The clay textured soils, when combined with the hilly micro-topography, contribute to appreciable run-off during snow-melt and heavy rain events.

During times of rain and snow-melt, the rills and small gullies collect and convey the surface drainage into the tributaries of Robinson Creek and finally into the main channel for discharge into the Grand River. The great majority of these rills and gullies are intermittent streams, in that they only carry drainage during times of wet weather or snow melt. Springs and seepage emanating from the north flank of the Onondaga Escarpment provide some base flow to Robinson Creek. Base flow from the clay soils to Robinson Creek is low because of the slowly permeable clay subsoils.

Wetlands on the property are a direct result of the hummocky micro-relief developed on clay soils. These wetlands collect and pond surface drainage.

Robinson Creek, its tributaries and lands bordering the Grand River below an elevation of approximately 183 m a.s.l., are prone to flooding during the spring.

This zone is shown on Figure 3 and is based on Grand River Conservation Authority data and observations of knowledgeable long term residents. Floods to these elevations are related to ice jamming in the Grand River Valley above Dunnville, just to the east of and down-gradient of the Order-in-Council lands.

3.5 GEOLOGY:

3.5.1 BEDROCK GEOLOGY:

The bedrock geology and stratigraphy of the study lands are described by Telford and Tarrant (1975). The Onondaga Escarpment bisects the area as it cuts east west through the site as shown on Figure 3.

South of the escarpment, Devonian limestone rocks of the Onondaga Formation underlie the clay plain lands at depths of 1 m to 5 m and form the caprock of the north-facing scarp. These sub-horizontally bedded sedimentary rocks dip regionally to the south and west at a fairly flat angle of 1° to 2°. About 3 m of rock are exposed in a small abandoned quarry located at the escarpment face as shown on Figure 3. This limestone is also the aquifer for drilled water wells.

The Bois Blanc Formation underlies the Onondaga Formation and forms much of the north-facing scarp face. The rock is also a limestone but with a higher shale and dolomite content.

About 600 m north of the escarpment edge the Bertie Formation, a bituminous dolomite of Silurian Age, has been interpreted. This formation also dips to the south beneath the escarpment and lies beneath almost all of that portion of the study lands between the scarp and the Grand River. The rock is deeply buried by soils.

The Salina Formation occurs beneath the Grand River Valley. This unit is a shale-dolomite complex that contains evaporites (salts) and brackish waters.

3.5.2 QUATERNARY GEOLOGY AND TERRAIN:

The area has been mapped and described in detail by Feenstra (1974). Subsoil details at depth are delineated by the Morrison Beatty Limited drill holes (1980) on the site along with backhoe pit locations.

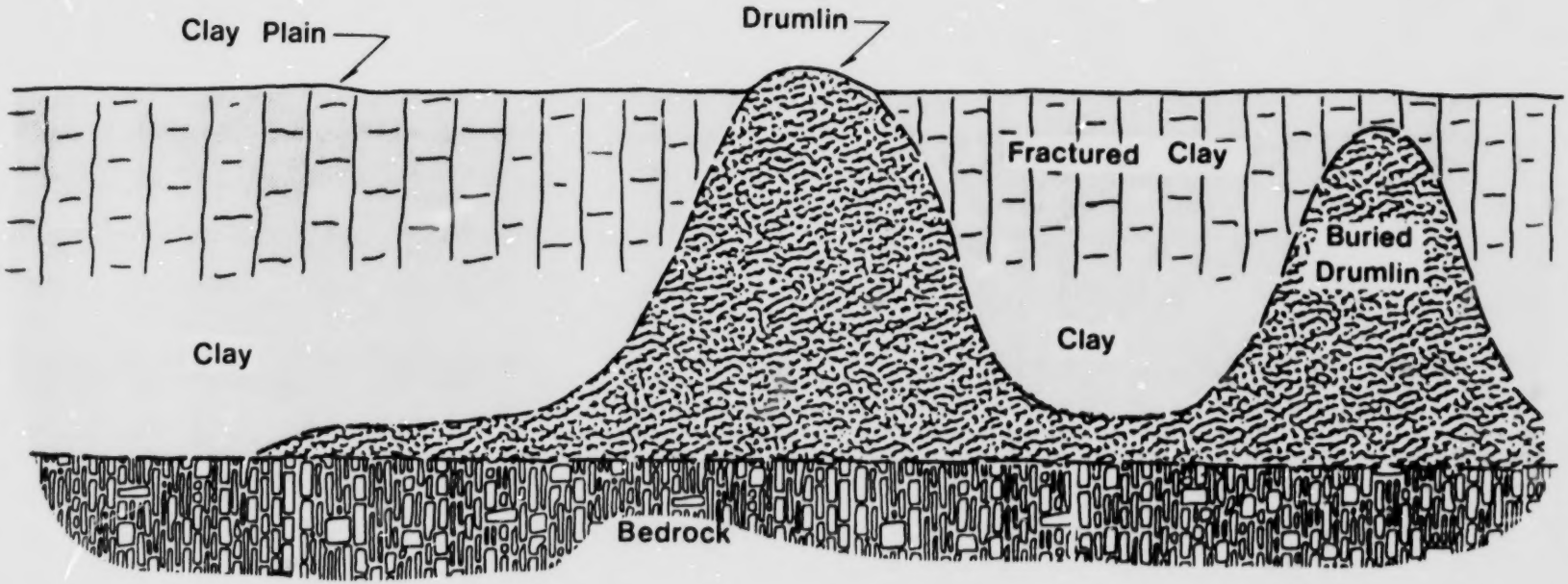
Through our research we have established the presence of 178 gas wells, 80 water wells, dug wells and cisterns, 21 boreholes drilled by Morrison Beatty Limited and a total of 29 test pits, 23 of which were dug by Gartner Lee Associates Limited.

As noted in the preceding section, soils to the south of the Onondaga Escarpment form a veneer of less than 5 m deep over the rock. These soils are of a glaciolacustrine origin and are of a silt and clay texture. The clays appear to be desiccated and fractured to depth due to weathering processes.

To the north of the escarpment drumlin landforms have been mapped on surface, as shown on Figure 3. These landforms are elongated oval shaped hills formed beneath the glacial ice and only the top surface of these are shown where they outcrop on the surface surrounded by the clays. Note the northeast to southwest orientation. These drumlins are composed of silty sand till soils with some sand and gravel seams. The tills are dense and stony but have a much higher permeability than the surrounding clays. This bouldery dense drift is often referred to as the Wentworth Till. Test pit #9 indicates the presence of a buried drumlin. Boreholes 13-80 and 16-80 of the Morrison Beatty study are also suspected to end in the stony till at refusal on boulders rather than bedrock. Since drumlins do occur in groups, there are likely others that are undetected at this time. Note the spacing of the outcropping drumlins on Figure 3 (in pocket at back of report) and the relationship of the drumlins to the clays on Figure 4.

Another anomaly occurs in the clays north of the escarpment to the northwest of the site. Gravel pits have been dug in sands covered by 1 m± of clay. These stratified sands have been interpreted as esker (glaciofluvial) deposits. This sand and gravel ridge has also been buried beneath the clays.

The clay plains north of the escarpment are of glaciolacustrine origin, that is, they are a complex of glacial till and stratified glacial lake sediments. The clays here also have a desiccated zone about 9 m deep below surface. Contours of drift thickness indicate a buried bedrock valley at the base of the Onondaga Escarpment



Schematic Cross Section

Fig. 4

(NOT TO SCALE)

approximately parallel to Robinson Creek. Borehole logs show the valley to be infilled with sands and gravels. Drift thickness along the buried valley ranges from 20 m to 40 m while thicknesses to the west range from 10 m to 25 m and to the east range from 10 m to 20 m.

3.6 HYDROGEOLOGY:

3.6.1 HYDROSTRATIGRAPHIC UNITS:

Five hydrostratigraphic units have been delineated in the South Cayuga study area. There are as follows:

(i) fractured clays
(ii) unfractured clays
(iii) silty sand till (drumlins)
(iv) sand and gravel (esker and fluvial)
(v) bedrock

The hydraulic parameters used in our analysis were derived from a combination of the Morrison Beatty Limited work and from studies done by our own company in similar hydrogeological environments. Therefore ranges of values as given here and in the appendix reflect those expected in such environments. Ranges of hydraulic parameter values are used to reflect the conditions expected at the South Cayuga Site. These values are detailed in Appendix 2. Technical descriptions of the five hydrostratigraphic units indicated above are also included in Appendix 2.

3.6.2 THE FLOW SYSTEM:

The hydrogeological conditions of the Order-in-Council lands were initially assessed in terms of the classical flow system approach. That is, recharge zones, intermediate flow zones and discharge zones. Only one aquifer exists within the study area, that is, the fractured limestone bedrock aquifer. This aquifer provides small supplies of potable ground water for both domestic and stock uses. Recharge to this aquifer is by direct infiltration in areas to the south of the Onondaga Escarpment, where drift thickness is shallow and through the esker complex. In addition, small volumes of recharge may be received via drumlin outcrops to the north of the escarpment. The water well information indicates a ground water divide at about the southern boundary of the study area, with flow to the south towards Lake Erie, and flow to the north towards the Grand River. It is likely that both Lake Erie and the Grand River are discharge areas with respect to the bedrock aquifer.

North of the Onondaga Escarpment drift thickness varies from 10 m to 40 m. The drift in most areas is saturated from near surface downwards. In most areas the drift comprises clayey material of low permeability. However, the upper 8 m to 9 m of the clay material appears fractured from borehole logs (Morrison Beatty Limited 1980). Ground water flow is via the fractures rather than through the soil pores in the weathered zone. The fracture porosity may also create large seasonal water table fluctuations.

3.6.3 GROUND WATER FLOW VELOCITIES:

In considering the area north of the Onondaga Escarpment for the siting of a secure landfill facility, the predictability of the hydrogeological setting was identified as one of the most important factors. The drift materials were assessed in relation to potential leachate migration pathways through these soils. The predictability of the leachate velocity and direction is necessary for designing buffer lands and for allowing sufficient lead time for mitigative measures if needed. In addition, the soils surrounding such a facility should protect local water resources. Details of flow calculations are appended.

Using existing available data, ground water velocities and travel times were calculated for all materials using established formulae. Lateral migration time through the fractured clay profile assuming no physico-chemical retardation of contaminants would be in the range of 6 m/a to 3000 m/a depending upon the input data. It is most likely that the lower end of this range is appropriate for much of the fractured material. Flow in this zone is predictable and with proper buffer design, sufficient lead-time could be provided for mitigative measures.

Vertical flow velocities through the unfractured clay material are very slow and range from 250 to 2,500 years per metre of flow path. The governing factor in vertical migration of contaminants is diffusion. Diffusion fronts were estimated to move at 140 to 500 years per metre of flow path.

Geological investigations indicated that buried drumlins may be present across the northern area. Hydraulic properties were estimated and together with prevailing conditions indicated that contaminant migration through the drumlins would range up to 20 years per metre of flow path. In addition, the possibility of a buried glaciofluvial landform (sand and gravel) was considered and a rate of movement of 0.02 to 0.2 years per metre of flow path was estimated.

Lateral ground water flow in the bedrock aquifer was estimated to range up to about 20 m/a. In addition, dilution within the aquifer of 1000 m from the point of breakthrough, assuming complete mixing and no dispersion of the plume, was calculated to vary from about 3 to 10 times depending upon initial conditions. Actual flow will be complex because of the fractured nature of the rock.

The calculations generally show that lateral flow through the clays is predictable but vertical flow towards the bedrock aquifer is unpredictable due to the possibility of buried high hydraulic conductivity material. Contaminant movement in the bedrock is rapid, limiting the lead time for remedial measures.

3.6.4 GROUND WATER QUALITY AND USE:

Water well locations are derived from field survey data and Ministry of the Environment water well records. Eighty drilled wells, dug wells and cisterns were located within the Order-in-Council boundary; only five of these wells

are located by M.O.E. records. See Figure 5. Not all homes were contacted during the field survey. Data from the M.O.E. Ground Water Probability Map (1973) was also used.

The majority of domestic water supplies come from cisterns which either collect runoff from roofs or store delivered water. New cisterns are generally prefabricated, sealed concrete boxes; older cisterns are shallow, hand-dug, and lined with stone. Only a few dug wells are located in the area, generally in the shallow sands over clay near the Grand River. Many of these dug wells are referred to as "spring" wells by residents.

Drilled wells comprise about 30-40% of the water wells within the Order-in-Council boundary. About half of these are known to obtain water from bedrock. Drilled wells in overburden generally obtain water from sands and gravels overlying bedrock. Several residents report that water is mineralized (iron or sulphur taste), and that water leaves a white sediment or that "black" water periodically occurs. Supplies are reported to be adequate for livestock (0.2 L/s to 3.0 L/s range). Most drilled wells were installed for livestock, and many are not currently in use.

3.7 GAS WELLS:

The locations of all of the gas wells cannot currently be ascertained with a high degree of certainty. Drilling

activity for natural gas has occurred in this area since the early 1900's. Local residents report that many dry holes were drilled at that time, and gas-producing wells abandoned in the first part of the century are not recorded. In particular, the northeast Order-in-Council lands are reported to have dry holes with no identified locations.

The gas producing formation occurs at approximately 200 m depth. Gas-bearing horizons are found in the Irondequoit and Reynales Formations. Producing wells are cased to production level, but are not all sealed or cemented in placed.

Most gas well owners report problems with water from upper bedrock formations flooding gas wells. Some wells are pumped several times a year to maintain gas flow.

Dry holes and wells abandoned before 1970 were apparently not grouted. Casings were pulled if possible when a well was abandoned. Often the casing was cut off and the remaining portion left below ground surface. Abandonment procedures generally consisted of blocking the upper part of the well with soil, cuttings, wood logs or any other available material.

DISCUSSION OF RESULTS

4-0

4.0 DISCUSSION OF RESULTS:

4.1 PREFACE:

Specifics of the waste quantities (amount of land required for disposal and thus site life) and waste characteristics (resultant leachate character) are the subject of extensive investigations not yet completed by Proctor & Redfern Limited. To provide a preliminary understanding of these aspects, meetings were held with Proctor & Redfern and the OWMC.

A contiguous site size of 40 ha minimum was deemed necessary, on the basis of the available information. Only treated wastes would be disposed at the landfill site. Specifics of the wastes and treatment technologies are not yet finialized. However, proven state-of-the-art technology for treatment of the waste is contemplated. It is expected that the resultant leachate from the wastes would likely be high in metals and inorganic chemicals depending on the pH of the waste which could be controlled.

A description of our approach and philosophy in assessing site suitability is provided in Section 2.1. The highlights of this philosophy are the need for a predictable setting with sufficient lead time to deal with engineering failure or accidental spills.

4.2 SITE SUITABILITY:

Of the 1,870 ha of Order-in-Council lands, at least one half are judged to be unsuitable in their natural state for the siting of a secure landfill facility. These lands are depicted on Figure 3, in the sleeve and described as:

- Flood Lands
- Bedrock Near Surface
- Drumlin and Buried Drumlim
- Buried Sand and Gravel
- Sand

The flood land is primarily associated with the low land adjacent to the Grand River and Robinson Creek. The extent of expected flooding shown is caused by ice jams on the Grand River northeast of the Order-in-Council lands.

Bedrock near surface comprises the southern half of the Order-in-Council land on top of the Onondaga Escarpment. Soils are desiccated clays, shallow and any leachate entering the bedrock would be in direct hydraulic connection with the bedrock aquifer that supplies domestic and livestock requirements. Ground water, and potentially contaminant, flow would be complex because of the fractured nature of the bedrock. These lands also constitute the primary recharge area for the bedrock aquifer.

Drumlins on surface north of the Onondaga Escarpment outcrop through the surrounding clay and extend vertically

downwards to the underlying bedrock aquifer. Our analysis and calculations indicate that ground water movement is moderately fast vertically downwards through these drumlins. As such the drumlins act as avenues for ground water recharge to the underlying aquifer. Buried Drumlins were also identified during our field analysis. The extent of the buried drumlins is not predictable nor is their depth below the surface clays although one test pit encountered a drumlin about 1 m below the clay surface.

Buried Sand and Gravel was also encountered in the study area north west of the Order-in-Council land. This sand and gravel is likely associated with an esker complex, a common feature found in association with drumlin fields. A sand and gravel pit has been developed in this deposit revealing about 1 m of clay overlying the granular material. Extraction had taken place to below the water table (approximately 8 m below ground surface). This low water table is at a slightly higher elevation than the Grand River (175±) indicating likely hydraulic continuity with the Grand River. Eskers are sinuous ridges of sand and gravel, in this case buried below the clay. This material would transmit contaminants quickly to the Grand River. At this stage it is not possible to positively conclude whether an esker exists within the Order-in-Council land. Further it is not possible to predict, if an esker does exist, its depth below the clay.

Sand on surface adjacent to the Grand River is relatively shallow overlying the local clay soils. However, ground water does move rapidly through this sand and discharges

into road side ditches and local drains. Some shallow dug wells obtain their water from these sands.

The remaining Order-in-Council lands consist of clay soils that are between 15 m to 20 m deep overlying the bedrock aquifer. These clays have a low permeability and effectively restrict contaminant movement. However, the likelihood of finding 40 contiguous hectares of clays free from buried drumlins and eskers is questionable at this time. Further detailed drilling and geophysical testing would be required to delineate the anomalies and even then, we would be uncertain that all subsurface anomalies had been discovered.

Abandoned gas wells, not properly sealed, constitute another problem factor at this site. It is highly unlikely that a 40 ha site could be located to completely avoid gas wells. This, coupled with the fact that no accurate location or sealing records were kept, constitutes a further uncertainty at this location. It is our opinion that these gas wells could be found during careful excavation of the proposed fill area and properly sealed. No technology, to our knowledge, would permit pre-excavation location of the wells with certainty. As such, the gas wells are of major concern, and would have to be dealt with but do not constitute a significant negative factor when considering the site suitability.

Conditions such as those described in the clay plain lead to the conclusion that these lands possess characteristics which render contaminant migration difficult to predict.

Even if 40 contiguous hectares could be found with no buried drumlins and eskers, the disposal options (entombment vs conventional trench-and-fill above surface) would be limited because of the limited clay thickness. As such, depending on the disposal option chosen, site life could be shortened. For example, if entombment is a desired disposal option, then the excavation depth and area requirements become constraints at this site for a long term facility. These conditions, within the remaining clay plain render it marginal for the development of a secure landfill from a hydrogeological perspective.

CONCLUSIONS

5-0

5.0 CONCLUSIONS:

The following conclusions are based on the preceding description of the Stage 1 Study results.

(i) *More than one half of the Order-in-Council lands are hydrogeologically unsuitable for the siting of a secure landfill facility. These lands consist of*

- the shallow soil area covering bedrock south of the Onondaga Escarpment,
- lands adjacent to Robinson Creek and the Grand River that are prone to flooding caused by ice jams on the Grand River,
- drumlins, buried and on surface, that occur within the clay plain soils north of the Onondaga Escarpment,
- sand and gravel areas, both buried and on surface located near the north edge of the Order-in-Council lands,

(ii) *The remaining clay plain lands are considered marginal for development of a secure landfill facility. The primary factors that support this conclusion are*

- the unpredictable nature of the stratigraphy as it relates to buried drumlins and eskers,

- the likelihood of finding 40 contiguous hectares without buried drumlins or eskers is questionable,
- limitations on landfill options and site life imposed by clay depths and location of drumlins.

Respectfully submitted,

GARTNER LEE ASSOCIATES LIMITED

R.E.J. Leech, B.Sc., M.Eng.Sc.,
Project Supervisor.

GLOSSARY OF SELECTED TERMS

6-0

6.0 GLOSSARY OF SELECTED TERMS:

Described below are some selected technical terms used in this report. Each term is quoted from a recognized source and these are referenced at the end of the glossary.

AQUIFER[1]

An *aquifer* is a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

CATION EXCHANGE CAPACITY[2]

The *cation exchange capacity* of a colloidal material is defined as the excess of counter ions in the zone adjacent to the charged surface or layer which can be exchanged for other cations. The cation exchange capacity of geological materials is normally expressed as the number of milli-equivalents of cations that can be exchanged in a sample with a dry mass of 100 g.

DESICCATION CRACK (FRACTURE)[3]

Crack formed by shrinkage of clay or clayey beds in the course of drying under the influence of the sun's heat.

DIFFUSION[3]

The spreading out of molecules, atoms, or ions into a vacuum, a fluid, or a porous medium, in a direction tending to equalize concentrations in all parts of a system.

DISPERSION, HYDRODYNAMIC[2]

There is a tendency for solute to spread out from the path that would be expected according to advective hydraulics of the flow system. This spreading phenomenon is called *hydrodynamic dispersion.*

DRUMLIN[4]

Oval hills of glacial till with smooth convex contours. In any area the *drumlins* all point in the same direction which is considered to be the direction of movement of the glacier which formed them.

ESKER[4]

A knobby, crooked ridge of coarse gravel and sand considered to be deposited by meltwater in crevasses and tunnels near the front of a glacier.

GLACIOFLUVIAL[3]

Pertaining to streams flowing from glaciers or to the deposits made by such streams.

GLACIOLACUSTRINE[5]

Pertaining to, derived from, or deposited in glacial lakes.

HYDRAULIC CONDUCTIVITY[1]

If a porous medium is isotopic and the fluid is homogeneous, the *hydraulic conductivity* of the medium is the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

HYDRAULIC GRADIENT[1]

The *hydraulic gradient* is the change in static head per unit of distance in a given direction.

HYDROGEOLOGY[6]

Hydrogeology can be defined as the study of ground water with particular emphasis given to its chemistry, mode of migration, and relation to the geologic environment.

HYDROSTRATIGRAPHIC UNIT[5]

A term for a body of rock having considerable lateral extent and composing, a geologic framework for a reasonably distinct hydrologic system.

ISOPACH[3]

A line, on a map, drawn through points of equal thickness of a designated unit.

LEACHATE[2] (paraphrased)

Buried refuse in sanitary landfills and dumps is subject to leaching by percolating water derived from rain or snowmelt. The liquid that is derived from this process is known as *leachate*.

LITHOLOGY[3]

The physical character of a rock, generally as determined megascopically or with the aid of a low-power magnifier.

PEDOLOGY[3]

The science which treats of soils, their origin, character, and utilization.

PERMEABILITY

In this report the term *permeability* is synonymous with hydraulic conductivity, see above.

PHYSIOGRAPHY[3]

The study of the genesis and evaluation of land forms.

POROSITY[1]

The *porosity* of a rock or soil is its property of containing interstices or voids and may be expressed quantitatively as the ratio of the volume of its interstices to its total volume.

POTENTIOMETRIC SURFACE[1]

The *potentiometric surface* is a surface which represents the static head.

STRATIGRAPHY[3]

That branch of geology which treats of the formation, composition, sequence, and correlation of the stratified rocks as parts of the earth's crust.

WATER TABLE[1]

The *water table* is that surface in an unconfined water body at which the pressure is atmospheric.

1. Lohman, S.W., 1973; Definitions of Selected Ground Water Terms - Revisions and Conceptual Refinements: U.S.G.S. Water-Supply Paper 1988.

2. Freeze, R.A. and Cherry, J.A., 1979; Ground Water: Prentice-Hall Inc., Englewood Cliffs, New Jersey 07632.

3. American Geological Institute, 1962; Dictionary of Geological Terms: Dolphin Books, Doubleday and Company, Inc., Garden City, New York.

4. Chapman, L.J. and Putnam, D.F., 1966; The Physiography of Southern Ontario: University of Toronto Press.

5. Bates, R.L. and Jackson, J.A., 1980; Glossary of Geology: American Geological Institute, Falls Church, Virginia.

6. Davis, S.N. and DeWiest, R.J.M. 1966; Hydrogeology: John Wiley and Sons, Inc., New York.

SELECTED BIBLIOGRAPHY

7-0

7.0 SELECTED BIBLIOGRAPHY:

Chanasyk, V., 1970
The Haldimand-Norfolk Appraisal *for* Ontario Ministry of Treasury, Economics and Intergovernmental Affairs, Vols. 1 and 2.

Chapman, L.J. and D.F. Putnam, 1966
The physiography of Southern Ontario, University of Toronto Press, 2nd Edition.

Cherry, J.A. et.al., 1979
Hydrogeologic properties and pore-water origin and age: clayey till and clay in south-central Canada. Presented at the Workshop in Low-Flow Low-Permeability Measurements in Largely Impermeable rocks, O.E.C.D. Nuclear Energy Agency and Int. At. Energy Agency, Paris.

Desaulniers, D.E. et.al., 1981
Origin, age and movement of pore water in argillaceous quarternary deposits at four sites in southwestern Ontario.
J. Hydrol. 50:231-257.

Dillon, M.M. Ltd., 1979
Selection of sites and handling systems facilities for storage of PCB wastes *for* Ontario Ministry of the Environment.

Energy, Mines and Resources Canada, 1981.
Listing of earthquake occurrences between 41° to 44° N and 76° to 84° W. *from* Data files, Earth Physics Branch, Division of Seismology and Geothermal Studies.

Feenstra, B.H., 1974
Quaternary geology of the Dunnville area, southern Ontario.
Ontario Division Mines Preliminary Map, P981 Geological Series (Scale 1:50,000).

_____,1981
Bedrock topography of the Dunnville area, Southern Ontario.
Ont. Geol. Surv. Preliminary Map P2402, Bedrock Topography Series (Scale 1:50,000).

Gartner Lee Associates Limited, 1979
Regional landfills - Site selection, design and approvals procedures *by* E.G. Anderson, Proc. Perspectives on Natural Resources Symp. III - Water, Lindsay.

_____, 1979
A general approach to landfill monitoring *by* P.K. Lee at National Solid Waste Conf., Winnipeg.

_____, 1981
Remote Sensing and sanitary landfills: a Canadian experience *by* Haynes, J.E. et.al. Symposium on Solving Environmental Problems in Northeastern U.S.A. and Eastern Canada, Geol. Soc. Am., Bangor, Maine.

Gartner Lee Associates Limited & International Environmental Consultants, 1981
Hydrogeological and related studies for South Cayuga - a Proposal for consulting services. 36 pp + Appendices.

Gore & Storrie Limited and Gartner Lee Associates Limited *(in prep.)*
Regional Municipality of Haldimand-Norfolk - Waste management study *for* Ontario Ministry of the Environment.

Grand River Conservation Authority, 1964
Floodline maps for parts of the Townships of North and South Cayuga (1:200 scale).

_____, 1981
Streamflow and corresponding elevation data for the Grand River from Lake Erie to Brantford.

Grisak, G.E. 1975
The fracture porosity of glacial till. Can. J. of Earth Sci. 12(3): 513-515.

Grisak, G.E. and J.A. Cherry, 1975
Hydrologic characteristics and response of fractured till and clay confining a shallow aquifer. Can. Geotech. Journal 12 (1):23-43

Grisak, G.E., et. al., 1976
Hydrogeologic and hydrochemical properties of fractured till in the interior plains region *In* "Glacial Till", Special publication No. 12 of the Royal Society of Canada.

Haldimand-Norfolk Organization for a Pure Environment, 1981.
Local water well and gas well survey results (unpublished).

International Environmental Consultants Ltd. and Gartner Lee Associates Limited, 1979.
Leachate impact study. A report for the Steel Company of Canada Limited (Lake Erie Development) 48 pp + Appendices.

Leach, W.W. 1975
Report of the Royal Commission Inquiry into the Grand River Flood, 1974 to the Lieutenant-Governor of the Province of Ontario. 93 pp.

MacLaren, James F. Ltd., 1979
Interim summary report to the Ministry of the Environment *for* Development of treatment and/or disposal sites for liquid industrial wastes and hazardous wastes.

MacLaren Engineers, Planners and Scientists Inc., 1980
Report on the siting of facilities and the management of liquid industrial and hazardous wastes in Ontario *for* Ontario Ministry of the Environment.

_____,1980
Technical report to the Ontario Ministry of the Environment on the siting of facilities and the management of liquid industrial and hazardous wastes in Ontario Annex One (1) - Need for waste management facilities and available technologies.

_____,1980
Technical report to .... in Ontario. Annex Two (11) - Site Selection

_____, 1980
Technical report to .... in Ontario. Annex Three (111) Ownership and transportation considerations.

Morrison Beatty Limited, 1980
Hydrogeologic investigation - Proposed waste management preserve - Township of South Cayuga *for* Ontario Land Corporation. 20 pp + Appendices and map.

Nash, R.C. and D.G. Glenney, 19?
"The Canal of the Grand River", St. Catharines Historical Society.

Ontario Ministry of the Environment (Several Years)
Water well records. (Unpublished original records)

_____, 1974
Ground Water probability, County of Haldimand. Water Resources Map 3112.

_____, 1978
Ontario Regional Municipality of Haldimand-Norfolk 1946-1975 Ontario Water Resources Bull. 2-23 Ground Water Series. 273 pp.

Ontario Ministry of Natural Resources, (Several Years)
Unpublished gas well records. Petroleum Resources Section, London, Ontario.

_____, 1973
The oil and gas potential of the 'Clinton Cataract' reservoirs of Norfolk County. Paper No. 73-2. 72 pp.

_____, 1976,77,78,79
Oil and gas exploration drilling and production summaries, 1974,75,76,77. Mineral Resources Branch, Petroleum Resources Section, Papers 75-1, 76-1, 77-1, 78-1 respectively.

_____, 1978
Aerial photography 1:10,000

Ontario Ministry of Transportation and Communications, 1981
Project status report - Access to South Cayuga liquid industrial and hazardous waste treatment facility (Preliminary).

Patterson, G.T., 1978
Preliminary Soils of the Cayuga-Canboro area of the Regional Municipality of Haldimand-Norfolk, southern Ontario. Ontario Instit. Pedology, Prelim. Map P.4 (Scale 1:25,000)

Reijntjes, C.G., 1981
Personal communication - Gas well experience at Stelco (Nanticoke Works)

Sanford, B.V., 1969
Geology, Toronto-Windsor Area, Ontario Geological Survey of Canada Map 1263A (Scale 1:250,000)

Telford, P.G. and G.A. Tarrant, 1975
Paleozoic geology of the Dunnville area, Southern Ontario. Ont. Div. Mines, Preliminary Map P988, Geological Series (Scale 1:50,000)

Topp, G.C. and M.R. Binns, 1976
Field measurement of hydraulic conductivity with a modified air-entry permeameter. Can. J. Soil Sci. 56: 139-147.

Topp, G.C. and W. Zebchuk, 1979
The determination of soil water desorption curves for soil cores. Can. J. Soil Sci. 59:19-26.

Topp, G.C., 1980
Electromagnetic determination of soil water content: measurements in coaxial transmission lines. Water Resources Research 16(3): 574-582.

Topp, G.C. et.al. 1980
The variation of 'in-situ' measured soil water properties within soil map units. Can. J. Soil Sci. 60:497-509.

van den Broek, B. 1980,
Preliminary soils of the Sweets Corner-Peacock Point areas in the Reg. Mun. of Haldimand-Norfolk, southern Ontario. Ont. Instit. Pedology, Prelim. Map P.7 (Scale 1:25,000).

Whitham K., et.al., 1970
Geophysics: The new seismic zoning map for Canada, 1970 Edition. The Canadian Underwriter

APPENDICES

I. FIELD OBSERVATIONS
   1. Back Hoe Test Pit Logs
   2. Water Level Elevations

II. HYDROGEOLOGICAL CALCULATIONS
   1. Hydrostratigraphic Units
   2. Hydrogeological Calculations
   3. Calculation of Attenuation by Cation Exchange

I. FIELD OBSERVATIONS

1. BACK HOE TEST PIT LOGS
2. WATER LEVEL ELEVATIONS

1.· BACK HOE TEST PIT LOGS

TABLE ____ SHEET ____

TEST PIT NO. 1

PROJECT NAME SOUTH CAYUGA - STAGE I **PROJECT NO.** 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION **DATE** October 5th, 1981
ELEVATION _____ **GEOLOGIST** D.F.M.

Depth m	Stati-graphy	Lithology	Remarks
0.0		TOPSOIL: grey black clay loam	wet to saturated
0.25	HALTON TILL	TILL: clay, some silt, brown blocky structure, few small stones and grits	wet to saturated
1.20		TILL: clay, grey to grey brown, blocky structure, few stones, some mottling to about 2.4 m, minor areas of lamination (siltier)	moist to wet (apl) some sweating on soil block faces
3.75	LACUSTRINE	CLAY: varved appearance, possibly lacustrine, grey to brown bands	moist to wet
4.0		Termination of test pit	no evidence of seepage, hole dry on completion.
			Some open desiccation fractures to about 1.0 m depth. Till below this depth has hairline fractures around block structures - steel blue mineralization on block faces.

Gartner Lee Associates Limited

TABLE ____ SHEET ____

TEST PIT NO. 2

PROJECT NAME SOUTH CAYUGA - STAGE I **PROJECT NO.** 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION **DATE** October 5th, 1981
ELEVATION _____ **GEOLOGIST** D.F.M.

Depth m	Stratigraphy	Lithology	Remarks
0.0		TOPSOIL: silty clay, brown	wet to saturated
0.30	HALTON TILL	TILL: clay, some silt, grey brown, blocky structure, moist to wet (apl), few stones and boulders up to 0.3 m size.	moist to wet (apl), moisture (sweating) on block fracture faces
3.00		CLAY and silt laminations - possibly lacustrine, grey brown	wet, moisture on bedding planes
3.65		Termination of test pit	no evidence of seepage, hole dry on completion
			Some open desiccation cracks in upper 0.75 m becoming hairline and very tight around soil block structures below this depth. Very few fractures evident below 3.0 m.

TABLE ____ SHEET ____

TEST PIT NO. 3

PROJECT NAME SOUTH CAYUGA - STAGE I — PROJECT NO. 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION — DATE October 5th, 1981
ELEVATION _____ — GEOLOGIST D.F.M.

Depth m	Stati-graphy	Lithology	Remarks
0.0		TOPSOIL: brown, clay, some silt	wet
0.2	HALTON	TILL: clay, some silt, slightly gritty, brown, blocky, hairline fractures around blocks.	moist
0.9	HALTON	TILL: clay, some silt, few small stones, brown to grey, hairline fractures, mineralization along fracture planes, sub-laminated	moist no evidence of seepage, hole dry on completion
3.51		Termination of test pit	

Gartner Lee Associates Limited

TABLE ____ SHEET ____

TEST PIT NO. 4

PROJECT NAME SOUTH CAYUGA - STAGE I **PROJECT NO.** 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION **DATE** October 5th, 1981
ELEVATION _____ **GEOLOGIST** D.F.M.

Depth m	Stati-graphy	Lithology	Remarks
0.0		TOPSOIL: clay, some silt, dark brown	wet
0.3	HALTON TILL	TILL: clay with some silt, changes from brown to brown/grey at 1.2 m, blocky structure. Till becomes sub-laminated at about 3.7 m. Tight fractures to total depth.	No seepage or beading, hole dry on completion.
4.3		Termination of test pit	

TABLE ____ SHEET ____

TEST PIT NO. 5

PROJECT NAME SOUTH CAYUGA - STAGE I
PROJECT NO. 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION
DATE October 5th, 1981
ELEVATION
GEOLOGIST D.F.M.

Depth m	Stati-graphy	Lithology	Remarks
0.0		TOPSOIL: clay, dark brown	wet to saturated
0.3	HALTON TILL	TILL: clay, massive, sub-laminated to blocky, few small stones, brown. Hairline fractures around blocks, steel grey colouration on fracture planes.	wet to saturated
3.5		Termination of test pit	Hole dry on completion.

Gartner Lee Associates Limited

TABLE ____ SHEET ____

TEST PIT NO. 6

PROJECT NAME SOUTH CAYUGA - STAGE I **PROJECT NO.** 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION **DATE** October 5th, 1981
ELEVATION _____ **GEOLOGIST** D.F.M.

Depth m	Stati-graphy	Lithology	Remarks
0.0		TOPSOIL: clay, some silt, brown	wet
0.2	HALTON TILL	TILL: clay, some silt, brown. Fracture aperture up to 2 mm.	wet
0.5	HALTON TILL	TILL: clay, minor silt, blocky, grey/brown hard to dense. Becoming sub-laminated below 3.1 m. Grey/blue staining on fracture plains. Some calcite crystallization.	moist to wet (apl)
3.7		Termination of test pit.	Hole dry on completion.

Gartner Lee Associates Limited

TABLE ____ SHEET ____

TEST PIT NO. 7

PROJECT NAME SOUTH CAYUGA - STAGE I — PROJECT NO. 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION — DATE October 6th, 1981
ELEVATION _____ — GEOLOGIST D.F.M.

Depth m	Stati-graphy	Lithology	Remarks
0.0		TOPSOIL: clay, grey/brown	saturated
0.2	HALTON TILL	TILL: clay, some stones up to 150 mm diameter, blocky, brown	saturated
0.5	HALTON TILL	TILL: clay, some stones up to 150 mm diameter, blocky, dense and hard. Becoming sub-laminated with depth. Open fractures with up to 2 mm aperture to .75 m depth below fractures are hairline relating to blocky till.	0.5 to 1.1 m saturated, drying with depth to moist.
3.4		Termination of test pit.	

TABLE ____ SHEET ____

TEST PIT NO. 8

PROJECT NAME SOUTH CAYUGA - STAGE I
PROJECT NO. 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION
DATE October 6th, 1981
ELEVATION
GEOLOGIST D.F.M.

Depth m	Stati-graphy	Lithology	Remarks
0.0		TOPSOIL: clay, grey/brown	saturated
0.2	HALTON TILL	TILL: clay, rare stones up to 150 mm diameter, blocky, brown	saturated
0.5	HALTON TILL	TILL: clay, rare stones and cobbles, hard and dense, blocky, becoming sub-laminated with depth. Open fractures in upper 0.5 m then becoming tight with depth.	saturated to 1.1 m, drying with depth to moist.
3.4		Termination of test pit.	

TABLE ____ SHEET ____

TEST PIT NO. 9

PROJECT NAME SOUTH CAYUGA - STAGE I — PROJECT NO. 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION — DATE October 6th, 1981
ELEVATION _____ — GEOLOGIST D.F.M.

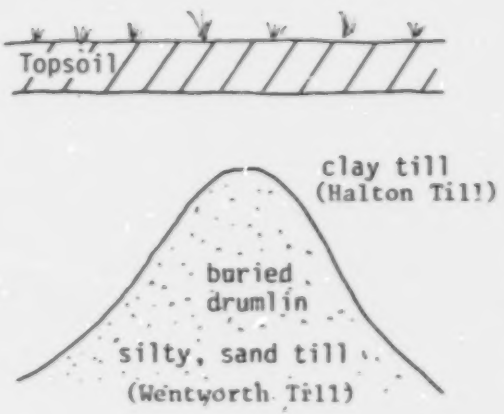
Depth m	Stratigraphy	Lithology	Remarks
0.0		TOPSOIL: clay, grey/brown	saturated
0.2	HALTON TILL	TILL: grey brown, clay, few stones and cobbles up to 150 mm in diameter, hard, dense, blocky, grey/brown. Open fractures in the upper 0.6 m and becoming tight with depth.	saturated to 0.6 m then drying with depth. Minor seepage at 0.5 m depth.
1.0	WENTWORTH TILL	TILL: medium brown silty, sandy, stoney, very dense till. No fractures observed.	dry to moist
2.4		Termination of test pit.	
			The contact between the two till units is shown schematically to the left.

TABLE ____ SHEET ____

TEST PIT NO. 10

PROJECT NAME SOUTH CAYUGA - STAGE I
PROJECT NO. 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION
DATE October 6th, 1981
ELEVATION
GEOLOGIST D.F.M.

Depth m	Stati-graphy	Lithology	Remarks
0.0		TOPSOIL: clay, grey/brown	saturated
0.2	HALTON TILL	TILL: clay, rare stones and cobbles, becoming harder and more dense with depth, sub-laminated.	saturated to 0.5 m then moist to wet on fracture plain.
3.4		Termination of test pit.	

TABLE ____ SHEET ____

TEST PIT NO. 11

PROJECT NAME SOUTH CAYUGA - STAGE I
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION
ELEVATION _____

PROJECT NO. 81-1002
DATE October 6th, 1981
GEOLOGIST D.F.M.

Depth m	Stati-graphy	Lithology	Remarks
0.0		TOPSOIL: clay, few stones, dark brown	saturated
0.2	HALTON TILL	TILL: clay, occasional stones and cobbles, blocky, dark grey. Fractured to total depth. Inclusions of calcite and brick red clay.	moist Fractures open and saturated to 0.8 m. Below 0.8 m fractures are tight around blocky textured clay. Fractures are irregularly spaced and orientated.
3.4		Termination of test pit.	

TABLE ____ SHEET ____

TEST PIT NO. 12

PROJECT NAME SOUTH CAYUGA - STAGE I
PROJECT NO. 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION
DATE October 6th, 1981
ELEVATION
GEOLOGIST D.F.M.

Depth m	Stratigraphy	Lithology	Remarks
0.0		TOPSOIL: clay, common boulders and stones, some silt, brown.	wet
0.3	HALTON TILL	TILL: clay, blocky, limestone, and granite boulders and stones, grey to brown. Inclusions of calcite. Fracture plains are blue grey to purple.	moist Desiccation fractures to about 0.8 m, then tight fractures around the blocky textured till.
3.4		Termination of test pit.	

TABLE ____ SHEET ____

TEST PIT NO. 13

PROJECT NAME SOUTH CAYUGA - STAGE I — PROJECT NO. 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION — DATE October 6th, 1981
ELEVATION _____ — GEOLOGIST D.F.M.

Depth m	Stratigraphy	Lithology	Remarks
0.0		TOPSOIL: dark brown clayey loam.	wet
0.35	HALTON TILL	TILL: clay, mottled, grey to dark grey. Very slightly silty, rare pebbles, brown	moist Desiccation fractures to 0.25 m. Blocky fractures below 0.25 m to total depth. Fracture plains have steel blue colouration.
3.1		Termination of test pit.	

TABLE ____ SHEET ____

TEST PIT NO. 14

PROJECT NAME SOUTH CAYUGA - STAGE I **PROJECT NO.** 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION **DATE** October 6th, 1981
ELEVATION _____ **GEOLOGIST** D.F.M.

Depth m	Stratigraphy	Lithology	Remarks
0.0		TOPSOIL: clay loam, dark brown	wet
0.25	HALTON TILL	TILL: clay, rare stones, grey/brown, calcite inclusions, blocky.	wet to moist
2.2	HALTON TILL	TILL: clay, grey, occasional brown colouration. Poorly fractured, blocky, laminated with depth (possible lacustrine)	wet
3.6		Termination of test pit.	
			Desiccation fractures in upper 0.8 m. Below 0.8 m fractures are tight and relate to blocky texture. In lower till unit there are very few fractures.

TABLE ____ SHEET ____

TEST PIT NO. 15

PROJECT NAME SOUTH CAYUGA - STAGE I
PROJECT NO. 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION
DATE October 6th,1981
ELEVATION
GEOLOGIST D.F.M.

Depth m	Stratigraphy	Lithology	Remarks
0.0		TOPSOIL: clay loam, common small pebbles, brown	moist
0.2	HALTON TILL	TILL: clay, dense, fairly common boulders and pebbles, grey/brown. Poorly defined lamination. Inclusions of calcite. Blocky texture.	moist
3.4		Termination of test pit.	
			Desiccation fractures are common in the upper 0.6 m. Below 0.6 m the fractures are tight and have a steel blue colouration.

TABLE ____ SHEET ____

TEST PIT NO. 16

PROJECT NAME SOUTH CAYUGA - STAGE I
PROJECT NO. 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION
DATE October 6th, 1981
ELEVATION ____
GEOLOGIST D.F.M.

Depth m	Stati-graphy	Lithology	Remarks
0.0		TOPSOIL: clayey loam, dark brown.	wet to moist
0.3		TILL: clay, dense, common calcite crystallization, rare stones, brown. Till becomes laminated at 2.8 m. Fractures are tight below 0.8 m	moist minor seepage at 3.28 m from a vertical fracture
3.3		Termination of test pit.	

TABLE _ _ SHEET _____

TEST PIT NO. 17

PROJECT NAME SOUTH CAYUGA - STAGE I PROJECT NO. 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION DATE October 7th, 1981
ELEVATION _____ GEOLOGIST D.F.M.

Depth m	Stratigraphy	Lithology	Remarks
0.0		TOPSOIL: clay, silty, brown	moist to wet
0.25		TILL: silty clay to clayey silt, mottled, grey/brown.	moist to wet
0.75		TILL: clay, blocky texture, grey to grey/brown. Steel blue colouration on fracture plains. Some sweating along fractures, few small stones.	moist
3.6		Termination of test pit	
			Desiccation fractures to 0.4 m below that fractures become hairline associated with blocky texture.

TABLE ____ SHEET ____

TEST PIT NO. 18

PROJECT NAME SOUTH CAYUGA - STAGE I
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION
ELEVATION _____

PROJECT NO. 81-1002
DATE October 6th, 1981
GEOLOGIST D.F.M.

Depth m	Stratigraphy	Lithology	Remarks
0.0		TOPSOIL: organic material, black.	saturated.
0.2	HALTON TILL	TILL: clay, blocky, mottled grey/brown.	saturated in upper 0.5 m becoming wet to moist with depth.
1.75		Termination of test pit.	
			Test pit dug beside wetland in wooded areas.

TABLE ____ SHEET ____

TEST PIT NO. 19

PROJECT NAME SOUTH CAYUGA - STAGE I
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION
ELEVATION _____

PROJECT NO. 81-1002
DATE October 7th, 1981
GEOLOGIST D.F.M.

Depth m	Stati-graphy	Lithology	Remarks
0.0		TOPSOIL: dark brown to black clay loam, wet to saturated.	wet to saturated.
0.25		TILL: clay, grey to grey brown, blocky structure, occasional small stones, steel blue (mineralization) staining on soil block faces.	wet to saturated to 0.75 m, becoming moist (apl) with depth, moisture sweating on fracture plains.
2.5		CLAY: alternating grey brown laminations (distorted varved appearance).	some moisture (sweating) on bedding planes, moist to wet (apl).
3.5		Termination of test pit	no evidence of seepage, hole dry on completion.
			Some open desiccation fractures evident to about 0.3 m depth. Till below this depth has hairline fractures around block structures.

TABLE ____ SHEET ____

TEST PIT NO. 20

PROJECT NAME SOUTH CAYUGA - STAGE I
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION
ELEVATION

PROJECT NO. 81-1002
DATE October 7th 1981
GEOLOGIST D.F.M.

Depth m	Stratigraphy	Lithology	Remarks
0.0		TOPSOIL: clay loam, black/brown	moist to wet
0.28	HALTON TILL	TILL: clay, mottled, brown	wet to saturated
0.8	HALTON TILL	TILL: clay, blocky, very little silt, occasional stones up to 150 mm diameter, grey to grey/brown.	moist to wet no seepage
3.8		Termination of test pit	hole dry on completion
			Desiccation fractures to 0.5 m closed due to saturation. Below 0.5 m fractures are hairline around blocky texture. Blue/grey staining on fracture surfaces.

TABLE ____ SHEET ____

TEST PIT NO. 21

PROJECT NAME SOUTH CAYUGA - STAGE 1 PROJECT NO. 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION DATE October 7th, 1981
ELEVATION ____ GEOLOGIST D.F.M.

Depth m	Stratigraphy	Lithology	Remarks
0.0		TOPSOIL: clay loam, brown/black	saturated to wet
0.25	HALTON TILL	TILL: silty clay, mottled, plastic, few cobbles up to 150 mm, grey/brown. Some calcite crystalization along block fractures, rare Queenston Shale pebble.	wet to saturated no seepage, some moisture on fracture surfaces
1.5	HALTON TILL	TILL: silty clay, plastic, grey to grey/brown. Small stones up to 50 mm, hard. Blue/grey colouration along fracture plains. Some calcite crystalization	moist to wet
2.4	LACUSTRINE	SILTY CLAY TO CLAY: laminated, may be modified, overridden lacustrine, grey/brown.	moist to wet becoming wet to saturated close to base of pit
3.6		Termination of test pit	
			Desiccation fractures to 0.75 m, hairline below

TABLE ____ SHEET ____

TEST PIT NO. 22

PROJECT NAME SOUTH CAYUGA - STAGE I — PROJECT NO. 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION — DATE October 8th, 1981
ELEVATION _____ — GEOLOGIST D.F.M.

Depth m	Stati-graphy	Lithology	Remarks
0.0		TOPSOIL: clay loam, black/brown	wet to saturated
0.25	HALTON TILL	TILL: clay, blocky, occasional stone up to 100 mm diameter, grey/brown	wet to saturated
1.25	HALTON TILL	TILL: clay, blocky, occasional stone up to 75 mm, grey to grey brown	moist to wet
2.75	LACUSTRINE	CLAY: laminated, plastic, grey/brown	saturated near bottom of pit. Minor seepage at toe.
3.8		Termination of test pit	
			Desiccation fractures in upper 1.25 m. Fractures becoming tight with depth. Fractures have a grey/blue staining on surface.

TABLE ____ SHEET ____

TEST PIT NO. 23

PROJECT NAME SOUTH CAYUGA - STAGE I **PROJECT NO.** 81-1002
CLIENT ONTARIO WASTE MANAGEMENT CORPORATION **DATE** October 8th, 1981
ELEVATION _____ **GEOLOGIST** D.F.M.

Depth m	Stratigraphy	Lithology	Remarks
0.0		TOPSOIL: clay loam, black	wet
0.25	HALTON TILL	TILL: clay, blocky, occasional stone up to 50 mm diameter, brown. Desiccation fractures closed.	wet (ape)
0.75	HALTON TILL	TILL: clay, blocky, hard, grey to brown/grey. Grey/blue staining and moisture on fracture plains.	moist, becoming wet to saturated at 3.0 m Minor seepage at toe
3.7		Termination of test pit	Hole dry on completion

2. WATER LEVEL ELEVATIONS

PROJECT 81-1002

TABLE ____ SHEET 1

GROUND WATER ELEVATIONS

BOREHOLE NUMBER	MONITOR No.	MONITOR Type	Ground Level ELEV. m.a.s.l.	top of pipe ELEV. m.a.s.l.	Depth to water 9/10/81 m	Water ELEV 9/10/81 m.a.s.l.
1-80		●	187.98	188.75	8.01	180.74
2-80			184.50	184.62	2.79	181.83
3-80	a	●	183.34	184.15	2.90	181.25
	b	●	183.45	184.11	2.77	181.34
	c	●	183.46	184.14	2.74	181.40
	d	●	183.49	184.14	2.50	181.64
	e	●	183.60	184.23	2.45	181.78
	f	▲	183.53	184.32	2.36	181.96
4-80		●	184.81	185.86	3.92	181.94
5-80		●	185.51	185.60	3.45	182.15
6-80		●		182.9	NF	
7-80		●		181.0	NF	
8-80		●	176.72	177.78	0.08	177.70
9-80		●		183.2	NF	
10-80		●	189.01	189.30	8.22	181.08
11-80		●	186.24	186.91	1.46	185.45
12-80		●		187.1	5.6	181.5
13-80		●		188.5	NF	
14-80		●		184.5	5.11	179.4
15-80	I	●		184.6	2.67	181.9
	II	●		184.6	3.08	181.5

● - Piezometer ▲ - Standpipe NF - Not Found

Gartner Lee Associates Limited

PROJECT 81-1002

TABLE ____ SHEET 2

GROUND WATER ELEVATIONS

BOREHOLE NUMBER	MONITOR No.	MONITOR Type	ELEV m.a.s.l.	Top of pipe ELEV. m.a.s.l	Depth to water 9/10/81 m	ELEV. 9/10/81 m
15-80	III	●		184.6	4.13	180.5
cont'd	IIII	▲		184.6	5.51	179.1
16-80		●		184.1	4.10	180.0
17-80		●	188.54	189.52	8.09	181.43
18-80		●	187.58	188.63	6.94	181.69
19-80		●		188.3	5.54	182.8
20-80		●		187.9	6.98	181.2
21-80		●		184.5	3.12	181.4

● - Piezometer ▲ - Standpipe

Gartner Lee Associates Limited

II. HYDROGEOLOGICAL CALCULATIONS

1. HYDROSTRATIGRAPHIC UNITS
2. HYDROGEOLOGICAL CALCULATIONS
3. CALCULATION OF ATTENUATION BY CATION EXCHANGE

1. HYDROSTRATIGRAPHIC UNITS

HYDROSTRATIGRAPHIC UNITS

DESCRIPTION

Five hydrostratigraphic units have been delineated in the South Cayuga study area. These are as follows:

(i) fractured clays
(ii) unfractured clays
(iii) silty sand till (drumlins)
(iv) sand and gravel (esker and fluvial)
(v) bedrock

In this section we briefly describe each hydrostratigraphic unit and summarize its hydraulic properties. A description of the physical hydraulic parameters is included in the following section of this appendix.

The fractured clays are the result of weathering and occur in the upper 8 m to 9 m of the clay plain as based on Morrison Beatty's test hole logs (1980). Our test pits confirmed this fracturing to 4 m. The average hydraulic conductivity is estimated to be in the 10^{-7} m/s to 10^{-5} m/s range although values as high as 10^{-4} m/s are reported. This is a secondary or fracture permeability. These fractures create a secondary porosity that varies between 0.005 and 0.01.

The unfractured clays exist beneath the weathered zone, i.e. below 9± m from surface. Their hydraulic conductivity is estimated to be in the range of 10^{-10} m/s to 10^{-9} m/s. This is three orders of magnitude slower than the weathered zone and is related to primary or intergranular permeability. Their average porosity is estimated to be 0.35. Clay size fractions in these soils are often greater than 50%.

The silty sand till contains usually less than 10% clay size material and hence its hydraulic conductivity is much higher than the clay. A reasonable hydraulic conductivity range is 10^{-7} m/s. A porosity of 0.25 is estimated.

The sands and gravels here are estimated to have a hydraulic conductivity in the range of 10^{-6} m/s to 10^{-5} m/s and a porosity of 0.25.

The bedrock has a similar hydraulic conductivity, i.e. 10^{-6} m/s to 10^{-5} m/s but a porosity of 0.05 is related to beds and fractures rather than via pores, i.e. secondary porosity.

2. HYDROGEOLOGICAL CALCULATIONS

HYDROGEOLOGICAL CALCULATIONS

PHYSICAL HYDRAULIC PARAMETER ESTIMATES

No detailed subsurface testing investigations were conducted by Gartner Lee Associates Limited. Therefore the hydraulic parameters used in this appendix have been derived from published information and data from our files.

HYDRAULIC CONDUCTIVITY VALUES were estimated from the Morrison Beatty work and from work done by our company in similar hydrogeological environments. Table 1 summarizes the ranges of hydraulic conductivity used for ground water velocity calculations in the present work.

TABLE 1 - Summary of hydraulic conductivity data.

Hydrostratigraphic Unit	Range of Hydraulic Conductivity
Fractured Clay	10^{-7} to 10^{-5}
Unfractured Clay	10^{-10} to 10^{-9}
Drumlin Material	10^{-8} to 10^{-7}
Esker Material	10^{-6} to 10^{-5}
Bedrock	10^{-5} to 10^{-6}

POROSITY VALUES for the various hydrostratigraphic units were estimated from data contained in our files and also published information. A summary of the porosity information is shown in Table 2.

TABLE 2 - Summary of porosity information.

Hydrostratigraphic Unit	Range of Porosity
Fractured Clay	0.005 - 0.01
Unfractured Clay	0.35
Drumlin Material	0.25 to 0.30
Esker Material	0.25
Limestone Bedrock	0.05

HYDRAULIC GRADIENT VALUES used to calculate ground water flow velocities were derived from measurements taken in the field in the monitors or estimated from topographic control and/or plotted information provided by Ministry of the Environment well records. A vertical gradient of 0.04 through the till material was measured in the Morrison Beatty piezometer nests. Lateral hydraulic gradients ranging from 0.02 to 0.05 for the fractured till were estimated from topographic information. A lateral hydraulic gradient in the bedrock aquifer of 0.003 was estimated from potentiometric information extracted from well records.

GROUND WATER MOVEMENT CALCULATIONS

The rate of ground water movement through soils can be estimated from the Darcian relation:

$$v = \frac{Ki}{n}$$

where, K = hydraulic conductivity L/T

i = hydraulic gradient L/L

n = porosity L^3/L^3

Using the information for each of the parameters presented in the above section it is possible to calculate both lateral and vertical velocities through the various hydrostratigraphic units. These calculations are summarized in Table 3.

TABLE 3 - Ground water movement calculations.

Hydrostratigraphic Unit	Hydraulic Conductivity (m/s) K	Hydraulic Gradient (m/m) i	Porosity n	Ground Water Velocity (m/a) V
Fractured Clay (lateral velocities)	10^{-7} to 10^{-5}	0.02 to 0.05	0.005 to 0.01	6 to 3000
Unfractured Clay (vertical velocity)	10^{-10} to 10^{-9}	0.04	0.35	0.0004 to 0.004
Drumlin Material (vertical velocity)	10^{-8} to 10^{-7}	0.04	0.25	0.05 to 0.5
Esker Material (vertical velocity)	10^{-6} to 10^{-5}	0.04	0.25	5 to 50
Bedrock (lateral velocity)	10^{-6} to 10^{-5}	0.003	0.05	2 to 20

The ground water velocity data can be used to predict break through times per metre of flow path or for a known flow path length. Table 4 below summarizes the ranges of ground water break through times for (a) a one metre flow path length, and (b) for a 10 m flow path length which may be considered representative of the drift thickness below the base of a facility within the study area.

TABLE 4 - Summary of ground water break-through times.

Hydrostratigraphic Unit	Time to Travel 1 metre (a)	Time to Travel 10 metres (a)
Fractured Clay (lateral)	0.0003 to 0.2	0.003 to 2
Unfractured Clay (vertical)	250 to 2500	2500 to 25000
Drumlin Material (vertical)	2 to 20	20 to 200
Esker Material (vertical)	0.02 to 0.2	0.2 to 2
Bedrock (lateral)	0.05 to 0.5	0.5 to 5

Ground water movement in the unfractured clay till indicates very slow movement i.e. 25,000 years for a 10 m flow path. In such poorly permeable material molecular diffusion dominates ground water (contaminant) movement. Using data by Desaulniers et.al. (1981) for similar materials in Southern Ontario we determined that the rate of movement through the unfractured clay would be in the range of 140 to 500 years per metre of flow path. These figures are about twice those calculated by the classical ground water flow system approach.

3. Calculation of Attenuation by Cation Exchange

CALCULATION OF ATTENUATION BY CATION EXCHANGE

For preliminary evaluation, a useful technique for considering the attenuation properties of soils is to assess their cation exchange capacity (CEC). There are other factors which retard or enhance contaminant flow. However, until details of the potential leachate chemical characteristics are known CEC calculations are useful tools for assessing the soils attenuation properties.

The assumptions listed below are based in part on data provided by the Ontario Waste Management Corporation and Proctor and Redfern as their design consultant. In addition, some data are provided from information on file in our office.

ASSUMPTIONS

- leachate cation loading is Ministry of the Environment drinking water guidelines times one hundred ie. 2500 meq/L.
- cation exchange capacity of the clay is 8 meq/100 g
- soil density is 1760 kg/m^3
- thus exchangable sites per m^3 of soil are 140,000

CALCULATIONS

For the purpose of the following calculations we will assume that leachate will emenate from the base of a proposed facility located in unfractured clay.

Ground water velocity calculations indicate that the vertical ground water velocity through the clay is of the order 0.0004 m/a. If we consider a $1m^2$ area then the volume of leachate that can be accepted by the clay equals 0.0004x0.35x1000

= 0.14 L/a

A volume of 0.14 L of leachate contains

0.14x2500 = 350 meq

of exchangeable cations.

A volume of 0.0004 m^3 of soil contains
0.004x140,000 = 56 meq
of exchangeable sites.

Thus, there are insufficient exchangeable sites to attenuate infiltrating leachate over short distances. To place these calculations into a better perspective we can consider the volume of waste ($60x10^6$ gallons per year as quoted in the McLaren Report) and a clay thickness below the proposed facility of 10 m.

The clay has an estimated porosity of 0.35, therefore, for each cubic metre the saturated volume is 350 L for a column of 10 m the saturated volume is 3500 L. A leachate loading of 2500 meq/L has been assumed. Thus the total cation loading in the 10 m soil column
= 3500x2500
= $8.7x10^6$ meq.

The soil has 140,000 exchangeable sites per cubic metre. Therefore, for the 10 m column $1.4x10^6$ sites are available only. This represents only 16% of the calculated cation loading due to leachate infiltration.